Use of Linear Regression and Analysis of Covariance to Build a Farm Level Regression Model for the Calibration of EMI sensor data (ECa) to soil salinity

Manjot Singh[1], Elia Scudiero[2] , Nigel W. Quinn[3], Sharon E. Benes[1]

[1]Dept. of Plant Science, California State University; [2]Dept. Of Environmental Sciences, University of California, Riverside and USDA-ARS Salinity Laboratory, Riverside, CA; [3]UC Berkeley National Laboratory

Introduction

- High-quality irrigation water is becoming scarce in California prompting the use of lower-quality, saline waters for irrigation.
- To maintain the long-term sustainability of forage production under irrigation with saline drainage water (4 to 8 dS/m), decision support tools are needed to monitor soil salinity and its spatial variability.
- One of these tools is the use of electromagnetic induction (EMI) sensors such as the Geonics EM38 and the CMD Mini-Explorer 6L (CMD-M6L Photo A) for ground surface mapping of soil apparent electrical conductivity (ECa) to generate spatial maps showing the distribution of salinity laterally and with depth.
- EMI sensor surveys can accurately map and assess the spatial variability in soil salinity. Still, considerable cost and time are required, particularly for the soil sampling that must be conducted for ground-truthing.
- This research was conducted at the San Joaquin River Improvement Project (SJRIP). This 6500-acre facility receives saline drainage water from 98,000 acres of productive farmland and reuses that water to irrigate 'Jose' tall wheatgrass, a highly salt-tolerant forage (Photos B, C). **Past EMI surveys at SJRIP were calibrated using 12 ground-truthing locations per field.**
- The long-term goal of this research is to provide rapid and accurate decision support tools to the managers of the SJRIP to maintain the sustainability of the forage production under saline irrigation.

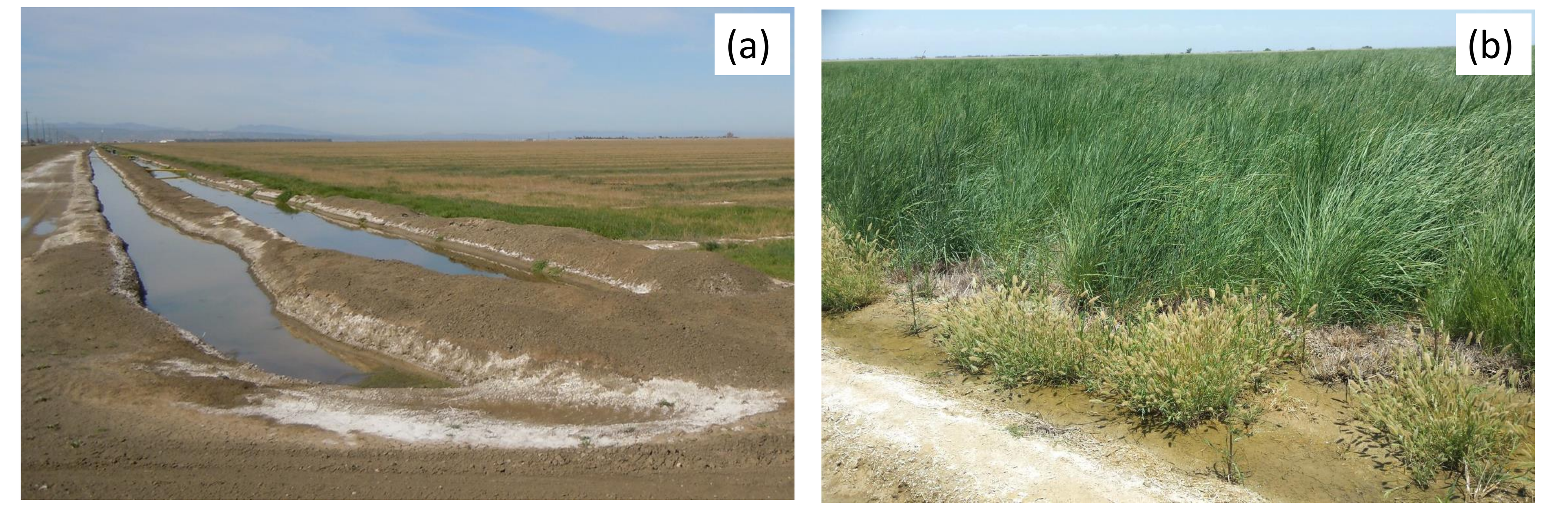
Objectives

- Map 9 forage fields collecting soil samples at 6 ground-truthing locations.
- Fields are 70 – 85 acres in size.
- Test three different regression strategies to examine the strength of the relationship between EMI sensor readings (ECa3, shallow and ECa5, deep reading) and predicted soil salinity (ECe, 0-120 cm)
  - Field Specific Regression (FSR)
  - Whole Farm Regression (WFR)
  - Analysis of Covariance (ANOCOVA)
- Determine whether the examined approaches can be used **to build a robust model for ECa calibration using minimal (6) ground-truthing locations.**

Photo: CMD Explorer sensor (middle, bright orange) for mapping soil salinity

Methodology

- In **December 2021, soil surveys** were conducted in **9 fields** at the SJRIP using the CMD-M6L sensor mounted on a plastic sled pulled behind an all-terrain vehicle equipped with a cm-scale GNSS unit to record geographical coordinates.
- **ESAP-RSSD software was used to determine either 6 ground-truthing locations** where soil was sampled from 0-120 cm in 30 cm increments for the determination of gravimetric soil moisture (GWC), pH, saturation percentage (SP) and salinity (ECe, electrical conductivity of the saturation soil paste extract).
- Pearson's correlation analysis and R^2 values from linear regression were compared to determine the degree of fit between the sensor readings of apparent electrical conductivity (ECa) and the actual soil salinity (ECe- saturation soil paste extract) for the ground-truthing soil samples.
- Model Development (EC_e prediction) and Evaluation: Leave one out approach (LOO) for model calibration and evaluation. Data for 5 of 6 GT locations used to calibrate the model and the remaining location was used to evaluate the model.
- For the relationship between observed and predicted soil salinity (EC_e), compare the coefficient of determination (R2), Root mean square error (RMSE), and Mean absolute error (MAE)



Photos: (a) saline drainage water entering the SJRIP and **(b)** 'Jose' tall wheatgrass stand under saline irrigation, Dec. 2021 (right).

Results

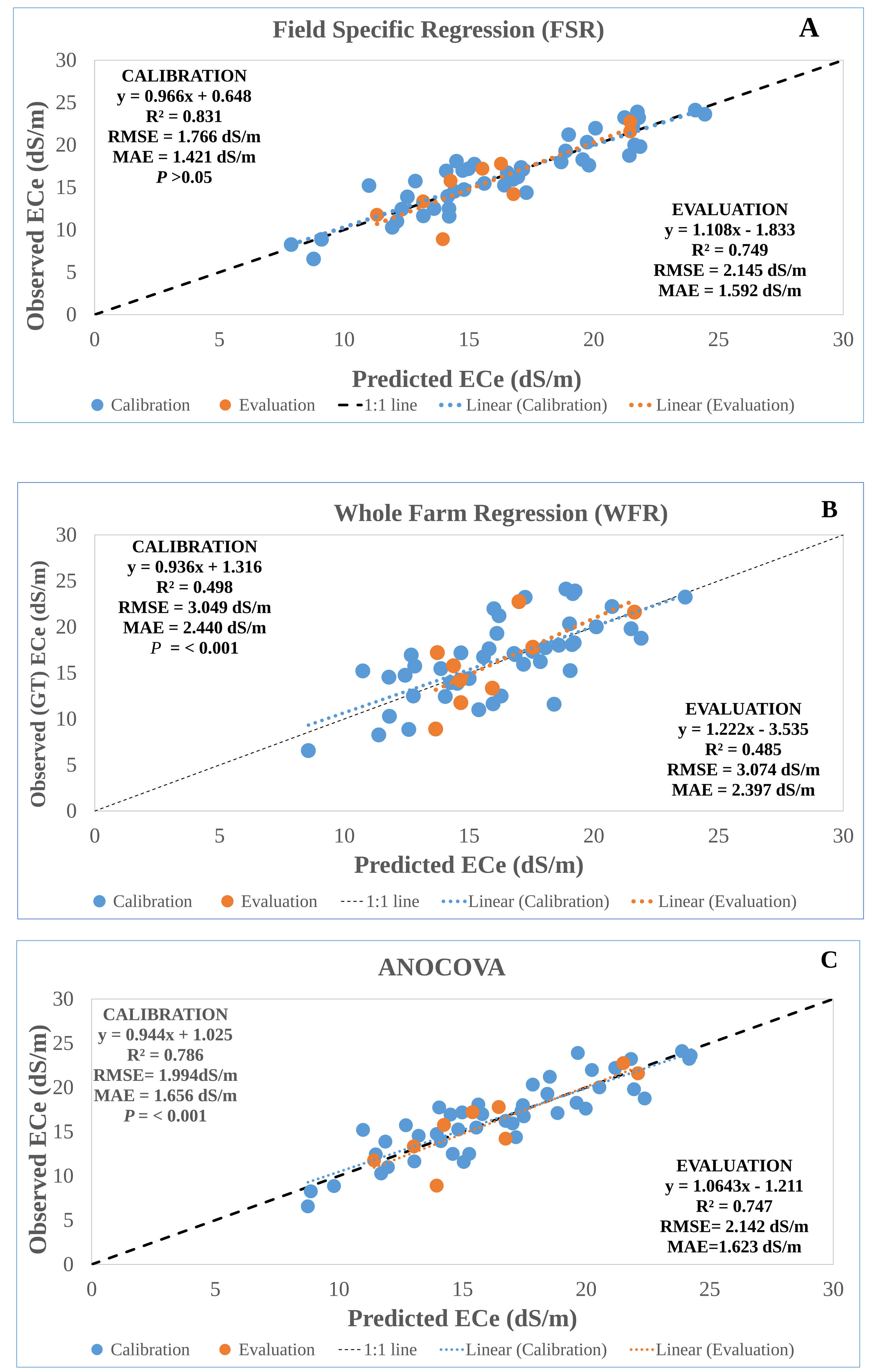


Fig. 1 (A, B, C): Correlation between Observed Electrical Conductivity (ECe, 0-120 cm) and Predicted ECe (from sensor data) resulting from 3 different regression approaches: (A) Field-specific calibration of ECa to ECe, (B) Whole Farm calibration and (C) calibration using ANOCOVA. RMSE = root mean square error and MAE = mean absolute error.

Acknowledgments: funding from the CSU-Agricultural Research Institute (ARI) (#21-02-127) and USDA-NIFA-SAS-CAP (project #2021-68012-35914). Field assistance from Rito Medina, Mauricio Soriano, and Pedro Hatem Squiapati. Computing assistance from Amninder Singh.

	RMSE				MAE		
FIELD	FSR	WFR	ANCOVA	FIELD	FSR	WFR	ANCOVA
10-6	4.13	3.34	3.71	10-6	3.48	2.94	3.07
11-2N	2.36	5.18	1.71	11-2N	1.97	4.95	1.43
13-1	3.19	2.46	2.86	13-1	2.65	1.66	2.15
13-2	3.49	3.12	2.76	13-2	3.25	2.42	2.67
13-6	0.81	2.4	1.43	13-6	0.64	2.08	1.31
13-7	2.01	1.81	2.03	13-7	1.79	1.29	1.67
14-1	2.48	1.62	1.83	14-1	1.96	1.26	1.51
14-2	3.44	3.53	2.45	14-2	2.54	2.73	2.11
18-3	1.91	3.37	1.85	18-3	1.51	3.09	1.32
Grand total	2.81	3.15	2.39	Grand total	2.2	2.49	1.92

Table 1. Comparison of errors associated with each regression approach; *Highlighted values are the chosen regression approaches (with the lowest errors)*

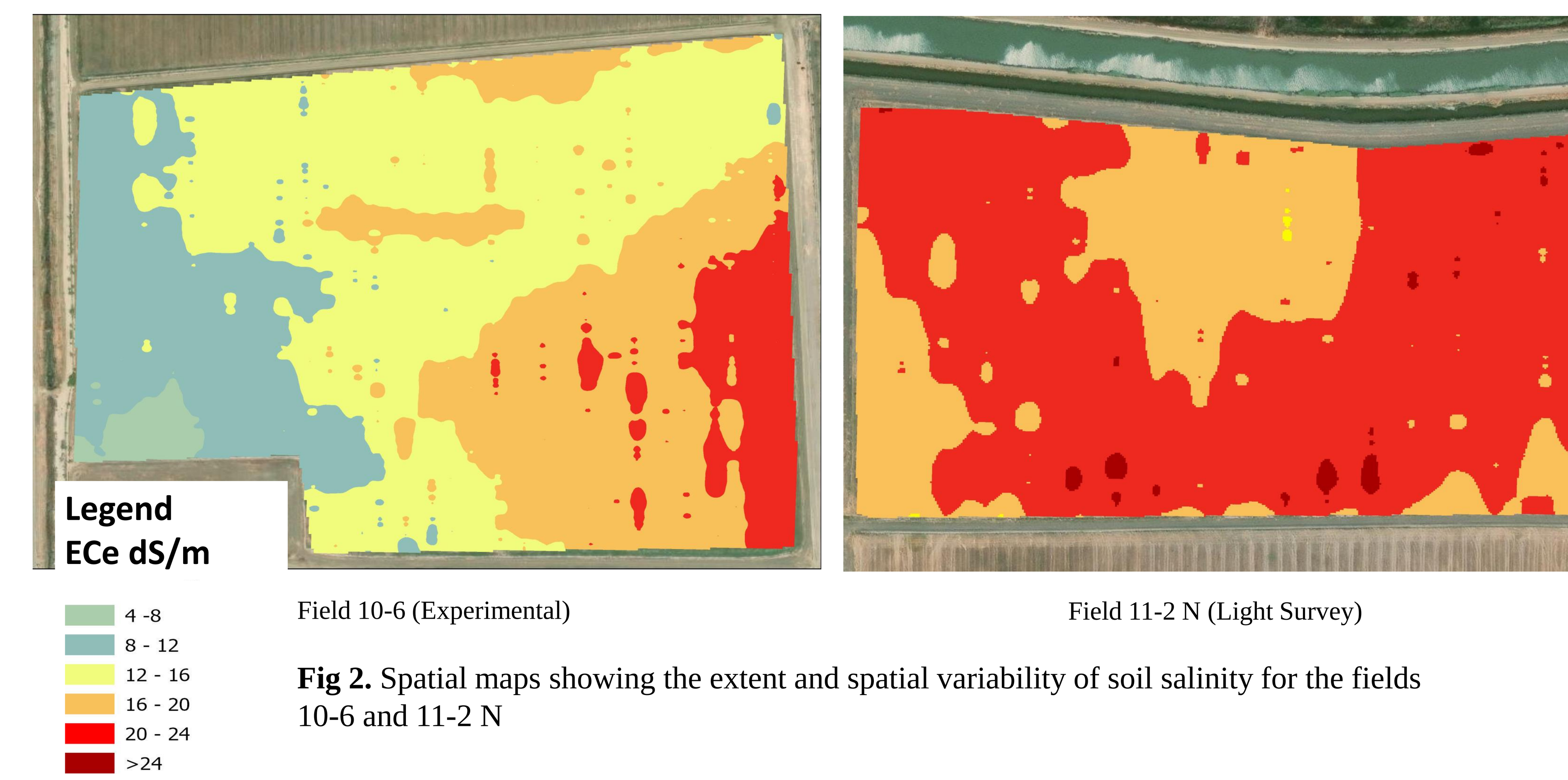


Fig 2. Spatial maps showing the extent and spatial variability of soil salinity for the fields 10-6 and 11-2 N

- Correlations were strongest for the deeper sensor reading when compared to the soil salinity averaged over the 120 cm depth (ECe 0-120 cm).
- **Fig. 1 (A, B, C):** when data from only 5 ground-truthing locations were used**,** all three regression models (FSR, WFR and ANOCOVA) had a relatively good fit between the Predicted ECe and the Observed ECe from the ground-truthing samples (R^2 0.485 to 0.749) with the MAE being lower for the FSR and ANOCOVA approaches, indicating less error when using the model to predict ECe.
- Overall the ANCOVA regression approach had among the lowest standard errors for the slope estimation for EC_a to EC_e calibration equations
- **Table 1** presents RMSE and MAE values for each field across three regression approaches. The approach with the lowest error for each field was selected for calibration, as shown in the maps for all nine fields in **Fig 2.**

Conclusions & Future work

- **ECa measurements should always be calibrated to ECe ground measurements for reliable soil salinity maps**.
- For an individual field ("field-specific") regression", 5 ground-truthing soil samples did not provide a sufficiently robust model. **However, the ANOCOVA regression approach is a viable alternative when multiple fields are surveyed and few soil samples per field are used to ground truth the ECa measurements.**
- Next round of soil surveys (October to November 2024). Consider only 6 locations for ground-truthing, both for light survey and experimental fields.
- Examine changes in soil salinity from December 2021 to Fall 2024 which follows an extended period of drought and shortages in saline drainage water that resulted in minimal irrigation of some forage fields at the SJRIP.